|   | Anti- — China Michael Marketin Microsoft (1) Marketin Andre Antiquities and Antiquities (1) Marketin (1) Marketin (1) Marketin (1) Marketin Marketin (1) Marketin    | in a full of the design the spin black to the product of the spin             |
|---|---|---|
|   | V. V. V. Gordon, and M. W. C.   | A control de de company de la la la la desagrapa a company de la decisión decisión decisión de la decisión de la decisión de la decisión decisión de la decisión decisión decisión de la decisión d            |
|   | Fundament   1915 to 19    | Community Build Andrew Belleting processing of Building Street (1997) and the Street (19            |
|   | The state of the s    | of Control & Allendo A            |
|   | in the fig. (b) in the fig. (c) is because the figure of the finterest of the figure of the figure of the figure of the figure o    | 40 de 10 de 20 de 10 de 10 de 10 de 20 de 20 de 20 de 20 de 10 de 20 de<br>10 de 20 de 20<br>20 de 20 de 20<br>20 de 20 de 20<br>20 de 20 de 20<br>20 de 20 |
|   | - Labora de Arganita describras, la estada de Arganita de Labora de Arganita de Arganit       | Annual St. Annual St. B. St. St. St. St. St. St. St. St. St. St   |
|   | தி முறிய நடிக்கு வெளியில் என்ற இருக்கும்.<br>இதற்கு நடிக்கு வெளியில் நடிக்கும் இருக்கும் நடிக்கும் விளியில் கிறியில் நடிக்கும்.<br>இதற்கு நடிக்கும் இருக்கும் நடிக்கும் நடிக்கும் இருக்கும் கடிக்கும் இருக்கும் இருக்கும். இது இருக்கும் இருக்கும<br>இது நடிக்கும் நடிக்கும்.   | Michel de Baser de Chile de Merca de La Company de La<br>La Company de La Company de<br>La Company de La Company de<br>La Company de La C   |
|   | en transport (f. 1904). De service de la companya d<br>La companya de la companya del companya del companya de la companya del la companya de la companya de la companya del la companya de la companya del l | (Philippe ) and the state of               |
|   | And to get the control of the contro    | Well Brick Berner de Brick Berner                |
|   | P. D.C. L.C. A. A. A. A. L. E. M. A.  | All familiations with the property of an extension regions by managing them becomes also the extension about the control of the property of the control of the property of the control of             |
|   | a long — da the in the part of the property of the property of the part of the    | The dign and state described to the former and the second section of the section of the second section of the section of the second section of the section of the second section of the            |
|   | The second section of the second seco    | ் வெள்ள பாட்டிய இரும் இரு<br>இரும் இரும் இர<br>இரும் இரும் இர   |
|   | 2. A second of the control of the       | ang plan in ang taon ng dia ng Bangaing Ban dia ang ang ang man ang ang ang ang ang ang ang ang ang a   |
|   | FIRES STORY AND STORY OF STORY OF A SET STORY OF A STORY OF A STORY OF A SET STOR    |   |
|   | g mengen pendadagan 21 mengenan andara dalam sagangan basa ang terbanah angan angan angan angan<br>nggarapatan gan galapat angan pangkaran pangkaran pendadan angan angan angan angan angan angan angan angan ang<br>nggarapat angan anga<br>Angan angan ang  | The second state of the se            |
|   | Lidas J. Anthold E. G. (1975) p. 10. (197       | in management (1948 til Artikal Ar Barriera destina en delega frajamente in gran frajamente in servicio del se<br>Antonio como del Referencia del servicio en alternativo del servicio del servicio del servicio del servicio del<br>La como del Referencia del Servicio del se      |
|   | The control of the co    | A first plant of the second               |
|   | (a) A of first B of the second of the sec       | A series of the series of t               |
|   | and the straint of the desired final properties of the straint        | Application of the second and the species of the second and the se            |
|   | April   Harde Sal Land Sal Sale   Sale Sale Sale Sale Sale Sale Sale Sale   | At the part of the            |
|   | of the term of the first hand to distinct a subsciencia for a self-in the star in the star    |   |
|   | 6 K. D. Mariji I. 1. And Mariji I. M. K. Berriffer Arrain in the Improving the property of the property of the Conference of the Confer       | And the first of the control of the             |
|   | And the second reserved by the second property of the second responsibilities of the second responsibilities of the second reserved by the second responsibilities of the second responsib    | and the control of th            |
|   | The state of the s    | And Market and the formal of the second seco            |
|   | The first of the problem of the Money Parker Anney on the first of the    | ria en en gill, meta en a transmissi figigle f <sub>er</sub> e politici film et de la fermination en en international de la companya del la companya de la companya del  |
|   | The second state of the second    | And the state of t            |
|   |   |   |
|   | The second secon    | To produce the product of the State of the S            |
|   |   | who the interest to the in the state of the             |
|   |   | And the state of the section of the             |
|   |   | And the Control of Selection in the Community of Selection and Selection in the Community of Selection in the Selection in the Community of Selection in the            |
|   | The state of the s    |   |
|   | A CONTROL OF THE PROPERTY OF T    | The state of the s            |
|   |   | The state of contract that is a particular base of the state of the st            |
|   |   | Takir ka kata da Mili ka shekara 1966 ya sa sa ka bara da sa ka da sa   |
|   |   |   |
|   |   |   |
|   |   |   |
|   |   | <ul> <li>And the second of the property of the second of the second</li></ul>       |
|   | A Committee of the Comm    | California della Carrio Carrio California della Carrio Carrio Carrio Carrio Carrio Carrio Carrio Carrio Carrio<br>Carrio Carrio Carrio<br>Carrio Carrio Car      |
|   |   | The first statement to be administrative of the statement            |
|   |   | And Control of Maries, and the Control of Maries and Andrews and A            |
|   | planter to the destruction of a company of the comp    |   |
|   |   |   |
|   | eria i di di<br>La constanti di di<br>La constanti di di<br>La constanti di di<br>La constanti di di<br>La constanti di   |   |
|   | သည်။ ကရာသေး ၂၈၂၈ က ကောင်းသို့ ကြိုင်းများသည်။ သည် သည် သည် သည်းသည် သို့သည် သို့သည် သို့သည် သို့သည် မိုကိုသည် သည<br>သည် သည် သည် သို့သည် မြိတ်သည်။ သို့သည် မိုင်သည် သည်သည် သည် သည် သည်သည် သည် သည် သည် သ  | graft - Sylvak in gerklatt, depresent gegrefende for der keine gegrefende som in der som en s            |
|   | n man a mag 17 a 18 complete from a martine of the minimum control program of the many and the man of the martine of the marti    |   |
|   | an graph of the first state of the state of t<br>The state of the state o | Kappinger i Amerika per gerindir ingen di Principier i in in in demokratika periodera di periodera periodera<br>Depokratika periodera (Bernatak periodera periodera di periodera di periodera di periodera periodera periodera<br>Depokratika periodera di periodera periodera periodera di periodera di periodera di periodera periodera di pe       |
|   | a particular de la companya del companya de la companya del companya de la companya de la companya de la companya del comp    | The first of the control of the cont            |
|   | and the state of t    |   |
|   | ျပည်။ သို့ ရေးသိုးသည်။ သို့ သို့ ရေးသို့ သောက်ရုံသော သောသောသည်။ ထုပ်ပြောင်းသွေးသို့သောက်သည်သော်သောသည်သော်သည်။<br>သူ့ ရေးသည်။ သို့သည် သူ့ အောင်သို့ သောသောသည်။ အသည် ရေးသည်သည်။ သည်သည် သည်သည် သည်သည်သည်သည်သည် သည်သည်။ အသည်သည်။<br>သည်သည်သည် သည်သည်။ သည်သည်သည်သည်သည်သည်သည်သည် သည်သည်သည်။ သည်သည်သည်သည်သည်သည်သည်။  | and the graph of the graph of the first of the graph of t            |
|   | ်မှုရှိ ရေးသည်။ သို့သည်။ ရှိချိန်း ရေးသည်။ လူသည်။ လုံးသည်။ သို့သည်။ သို့သည်။ သည်။ သို့သည်။ သို့သည်။ သို့သည်။ သည်။<br>သည်။ သည်။ သည်။ သို့သည်။ သို့သည်။ သည်။ သည်။ သည်။ သည်။ သည်။ သည်။ သည်။  | and the second s            |
|   | the second secon    | en de la tras primera apparata por la promisión de la compania de la production de la participación de la part<br>La programa de la compania de la deligión de la programa de la configue de la programa de la programa de la po<br>La programa de la programa del programa de la programa del programa de la programa del prog      |
|   | i de la gentrale de Mentelle de l'ambande portrollère de proprière de service de la companya de la familia de la companya del la companya del la companya de la companya del la com    |   |
|   | gar ingelegetette til til til et i generalle gar at generalle gjelde stadet et blevering folge en engegetet et<br>Erit forste til 1970 til 1970 stadet i trendet grende gjelde gjelde gjelde gjelde gjelde gjelde gjelde gjelde g<br>I gjelde gjelde i 1970 til 1970 stadet gjelde g   | The state of the s            |
|   | ுக்கும். இன் பெறு பாறு விறையின்ற திறையின் பிறுக்கும் இறிப்பிடிய வெறிவிறுக்கும் இதியில் இருக்கும்.<br>இன் முற்றத் திறையின் நிறையின் இறிவிறுக்கும் இருக்கும் விறுக்கும் இருக்கும் இருக்கும் இருக்கும் இருக்கும் இருக்கும்.<br>அம் முறுத் துகையில் புதுவையின் முறுக்கும் அருக்கும் இருக்கும் இருக்கும் விறுக்கும் விறுக்கும் விறுக்கும் இருக்கும்.<br>அம் இருக்கும் இருக்கும் இருக்கும் இருக்கும் அம் இருக்கும் விறுக்கும் அனின் இருக்கும்.  |   |
|   | A. D. W. C. L. Company of the Com       | <ul> <li>In the first term of the property of the property</li></ul>      |
| The second se | ** ** ** ** ** ** ** ** ** ** ** ** **  | The control of the co            |
|   | S. S. Saller, A. B. Saller, and A. Saller, and A       |   |
|   | The control of the co    | Control of the party of the par            |
|   | And the second of the second o    |   |
|   | gen Britani. Den der die geschenderen Philologiene geschiederen geschiederen der  | i militari kan kan ili kan sa gunusa kan sa na mana kan sa kan kan sa kan sa kan sa kan sa kan sa kan sa kan s<br>A kan sa ka<br>Kan sa kan s   |
|   | ga attenti i til della i della distribita i della sittatta contrata di della i sittatta i distribita i di trapportori di trapp    | the first of the first of the second             |
|   | en presente de la collection de la constituent de estable de presente de la constituent de la constituent de l<br>en la gant de la constituent de la constituent de la constituent de la collection de la constituent de la constituen  | i vertica de la companya de la comp<br>La companya de la co<br>La companya de la co  |
|   | natività è proprio della propr    | The state of the s            |
|   | The state of the s    | \$100 PATE STORES AND TRANSPORTED TO THE PROPERTY AND THE            |
|   | [Addition Action 6] Birthi State Control        | The district Application (Continues on the Continues on t            |
|   |   |   |





# NAVAL POSTGRADUATE SCHOOL

Monterey, California



# THESIS

P157583

ON CAPTURE EFFECT OF FM DEMODULATORS

by

Park Soon Sang

March 1989

Thesis Advisor:

Glen A. Myers

Approved for public release; distribution is unlimited



| 1a REPORT SECURITY CLASSIFICATION UNCLASSIFICATION UNCLASSIFICATION AUTHORITY  2a SECURITY CLASSIFICATION AUTHORITY  2b DECLASSIFICATION DOWNGRADING SCHEDULE  4 PERFORMING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  6a NAME OF PERFORMING ORGANIZATION (If applicable) 6c ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8a NAME OF FUNDING/SPONSORING ORGANIZATION  8b OFFICE SYMBOL (If applicable) 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  15 MONITORING ORGANIZATION Naval Postgraduate School  16 ADDRESS (City, State, and ZIP Code)  17 ADDRESS (City, State, and ZIP Code)  18 NAME OF FUNDING/SPONSORING ORGANIZATION  19 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  10 OFFICE SYMBOL (If applicable)  10 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  11 OMB NOTICE SYMBOL (If applicable)  12 OMB NOTICE SYMBOL (If applicable)  13 DISTRIBUTION AVAILABILITY OF REPORT Approved for public release; distribution is unlimited  15 MONITORING ORGANIZATION REPORT NUMBER(S)  16 OFFICE SYMBOL (If applicable)  17 OMB NOTICE SYMBOL (If applicable)  18 OFFICE SYMBOL (If applicable)  19 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  18 OFFICE SYMBOL (If applicable) |  |  |  |  |
|---|--|--|--|--|
| 1a REPORT SECURITY CLASSIFICATION UNCLASSIFICATION UNCLASSIFICATION AUTHORITY  2a SECURITY CLASSIFICATION AUTHORITY  2b DECLASSIFICATION DOWNGRADING SCHEDULE  4 PERFORMING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  6a NAME OF PERFORMING ORGANIZATION (If applicable) 6c ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8a NAME OF FUNDING/SPONSORING ORGANIZATION  8b OFFICE SYMBOL (If applicable) 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  15 MONITORING ORGANIZATION Naval Postgraduate School  16 ADDRESS (City, State, and ZIP Code)  17 ADDRESS (City, State, and ZIP Code)  18 NAME OF FUNDING/SPONSORING ORGANIZATION  19 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  10 OFFICE SYMBOL (If applicable)  10 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  11 OMB NOTICE SYMBOL (If applicable)  12 OMB NOTICE SYMBOL (If applicable)  13 DISTRIBUTION AVAILABILITY OF REPORT Approved for public release; distribution is unlimited  15 MONITORING ORGANIZATION REPORT NUMBER(S)  16 OFFICE SYMBOL (If applicable)  17 OMB NOTICE SYMBOL (If applicable)  18 OFFICE SYMBOL (If applicable)  19 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER  18 OFFICE SYMBOL (If applicable) |  |  |  |  |
| UNCLASSIFIED  2a SECURITY CLASSIFICATION AUTHORITY  2b DECLASSIFICATION / DOWNGRADING SCHEDULE  4 PERFORMING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  6a NAME OF PERFORMING ORGANIZATION  6b OFFICE SYMBOL  ((If applicable)  6c ADDRESS (City, State, and ZIP Code)  6d OFFICE SYMBOL  (If applicable)  7a NAME OF MONITORING ORGANIZATION  Naval Postgraduate School  6c ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8d OFFICE SYMBOL  ((If applicable)  8d OFFICE SYMBOL  ((If applicable)  9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER(S)  | proved<br>0 0704-018                       |  |  |  |
| Approved for public release; distribution is unlimited  4 PERFORMING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  6a NAME OF PERFORMING ORGANIZATION  Naval Postgraduate School  6c. ADDRESS (Crty, State, and ZIP Code)  Monterey, California 93943-5000  8a NAME OF FUNDING/SPONSORING ORGANIZATION  Noterey, California 93943-5000  8b Office SYMBOL (If applicable)  ORGANIZATION  9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER(S)  | 16 RESTRICTIVE MARKINGS                    |  |  |  |
| distribution is unlimited  4 PERFORMING ORGANIZATION REPORT NUMBER(S)  5 MONITORING ORGANIZATION REPORT NUMBER(S)  6a NAME OF PERFORMING ORGANIZATION  6b OFFICE SYMBOL (If applicable)  Naval Postgraduate School  6c. ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8a NAME OF FUNDING/SPONSORING ORGANIZATION  Nordanization (If applicable)  9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER(S)  9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER(S)   |  |  |  |  |
| 6a NAME OF PERFORMING ORGANIZATION  Naval Postgraduate School  6c. ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8a NAME OF FUNDING/SPONSORING ORGANIZATION  (If applicable)  7a NAME OF MONITORING ORGANIZATION  Naval Postgraduate School  7b ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8b Office SYMBOL (If applicable)  9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER ORGANIZATION   |  |  |  |  |
| Naval Postgraduate School  6c. ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8a NAME OF FUNDING/SPONSORING ORGANIZATION  (If applicable)  (If applicable)  Naval Postgraduate School  7b ADDRESS (City, State, and ZIP Code)  Monterey, California 93943-5000  8b Office SYMBOL (If applicable)  9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER (If applicable)   | 5 MONITORING ORGANIZATION REPORT NUMBER(S) |  |  |  |
| Monterey, California 93943-5000 Monterey, California 93943-5  8a NAME OF FUNDING/SPONSORING ORGANIZATION Bb OFFICE SYMBOL (If applicable)  9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER (If applicable)   |  |  |  |  |
| 8a NAME OF FUNDING /SPONSORING ORGANIZATION 8b OFFICE SYMBOL 9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMB (If applicable)   | 7b ADDRESS (City, State, and ZIP Code)     |  |  |  |
| ORGANIZATION (If applicable)  |  |  |  |  |
|   | C **                                       |  |  |  |
| 8c. ADDRESS (City, State, and ZIP Code) 10 SOURCE OF FUNDING NUMBERS  |  |  |  |  |
|   | VORK UNIT                                  |  |  |  |
| 12. PERSONAL AUTHOR(S) PARK, Soon-Sang  13a TYPE OF REPORT Master's Thesis FROMTO14 DATE OF REPORT (Year, Month, Day) 15 PAGE CO 16 SUPPLEMENTARY NOTATION  12. PERSONAL AUTHOR(S) PARK, Soon-Sang 14 DATE OF REPORT (Year, Month, Day) 15 PAGE CO 1989 March 46  | UN-  |  |  |  |
| 17 COSATI CODES 18 SUBJECT TERMS (Continue on reverse if necessary and identify by block in   | umber)                                     |  |  |  |
| FIELD GROUP SUB-GROUP FM Demodulator, Capture effect  | ator, Capture effect                       |  |  |  |
| The reception of FM carriers is characterized by a capture effect the message of the dominant carrier is recovered when two or more carriers are present. This research uses a computer to form a type average of the instantaneous frequency of the receiver input. The establish that averaging (smoothing or lowpass filtering) of the instantaneous frequency reveals the capture effect. The effect or capture of bandwidth and amplitude ratio for the case of two carrier revealed. The results show that capture can occur when two carrier separated by as little as 0.17dB in amplitude.  | FM<br>De of<br>e resu<br>lers i            |  |  |  |
| QUNCLASSIFIED/UNLIMITED SAME AS RPT DTIC USERS UNCLASSIFIED   | UNCLASSIFIED                               |  |  |  |
| MYERS, Glen A. 226 TELEPHONE (Include Area Code) 62MV 62MV  | U.   |  |  |  |

DD Form 1473, JUN 86

Approved for public release: distribution is unlimited.

On Capture Effect of FM Demodulators

by

Park, Soon Sang Captain, Republic of Korea Army B.S., Korea Military Academy, 1984

Submitted in partial fulfillment of the requirments for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL March 1989

## ABSTRACT

The reception of FM carriers is characterized by a capture effect whereby the message of the dominant carrier is recovered when two or more FM carriers are present. This research uses a computer to form a type of average of the instantaneous frequency of the receiver input. The results establish that averaging (smoothing or lowpass filtering) of the instantaneous frequency reveals the capture effect. The effect on capture of bandwidth and amplitude ratio for the case of two carriers is revealed. The results show that capture can occur when two carriers are separated by as little as 0.17 dB in amplitude.

P157583

# TABLE OF CONTENTS

| I.   | INT  | NTRODUCTION                            |    |
|------|------|--|----|
| II.  | BAG  | CKGROUND                               | 3  |
|      | A.   | EQUATION FOR FM CARRIER                | 3  |
|      | В.   | CAPTURE EFFECT                         | 4  |
|      | С.   | ANALYSIS                               | 4  |
| III. | SIM  | ULATION PROCEDURE                      | 13 |
|      | A.   | WAVEFORM GENERATION                    | 13 |
|      | В.   | COUNTING                               | 14 |
|      | С.   | AVERAGING                              | 15 |
| IV.  | SIM  | ULATION RESULTS                        | 17 |
|      | A.   | EFFECT OF N (AVERAGING TIME)           | 18 |
|      | В.   | EFFECT OF SIGNAL AMPLITUDE RATIO       | 18 |
|      | C.   | EFFECT OF MODULATION INDEX             | 18 |
|      | D.   | EFFECT OF CARRIER FREQUENCY DIFFERENCE | 19 |
| V.   | COI  | NCLUSIONS AND RECOMMENDATIONS          | 30 |
| APF  | PEND | IX –PROGRAM LIST                       | 31 |
|      | A.   | MAIN                                   | 32 |
|      | В.   | CHIRPGEN                               | 33 |
|      | С.   | WAVEGEN                                | 34 |
|      | D.   | COUNT                                  | 35 |
|      | E.   | SAMPLE                                 | 37 |

## I. INTRODUCTION

Radio communication usage continues to expand because the military and commercial markets seek (1) personalized service such as paging and cellular applications, (2) ever greater exchanges of text and data (facsimile, computer networking), and (3) transfer of high quality signals (television). The messages are "traffic". The carriers are sine waves.

There are two primary ways of carrying messages using sinusoids. The message can cause to vary (modulate) the amplitude or the argument (angle) of the sinusoid. These are called amplitude modulation (AM) and angle modulation (AM) respectively.

Amplitude modulation can assume various forms such as double sideband with carrier, double sideband suppressed carrier and single sideband. Angle modulation can be either frequency modulation (FM) or phase modulation (PM). With analog messages, there is little difference between FM and PM. In fact, FM hardware would be used should PM be chosen. Consequently, PM with analog messages is, in practice, reduced to FM. [Ref. 1: pp. 198–199]

Frequency modulation exhibits several interesting characteristics not shared by AM. Two such characteristics are threshold effect and capture effect. The threshold effect relates to the quality (signal—to—noise ratio) of the demodulator output as a function of the quality of the received signal (demodulator input). Below "threshold" quality of the input, the output quality deteriorates rapidly. The capture effect relates to the ability of the demodulator to recover the message of the dominant carrier when two or more FM carriers are present.

This research is concerned with the capture effect of FM. Computer simulation is used to verify an idea concerning the reason for (origin of) the capture effect of FM demodulators.

Background information on FM and the capture effect is presented in chapter II of this thesis. Chapter III describes the computer simulation procedure and program. Results of the simulation are contained in Chapter IV. Conclusions and recommendations are listed in chapter V. The computer program is listed in the Appendix. A list of references is provided.

#### II. BACKGROUND

# A. EQUATION FOR FM CARRIER

An angle modulated sinusoid is expressed as

$$s(t) = B\cos[\phi_{j}(t)] \tag{2.1}$$

where the constant B is the carrier peak amplitude. A complete oscillation cycle occurs whenever the argument  $\phi_i(t)$  changes by  $2\pi$  radians. The instantaneous frequency of the angle modulated wave s(t) is defined by

$$f_i(t) \triangleq \frac{1}{2\pi} \frac{d\phi_i(t)}{dt}$$
 (2.2)

Frequency modulation is that form of angle modulation for which the instantaneous frequency  $f_i(t)$  varies in accordance with the baseband signal or message voltage m(t). Typically, a linear relationship is chosen so that

$$f_i(t) = f_c + k_f m(t) \tag{2.3}$$

where  $f_c$  is the frequency of the unmodulated carrier and the constant  $k_f$  represents the frequency sensitivity (in Hertz per volt) of the modulator. From Eqs. (2.2) and (2.3), the angle  $\phi_i(t)$  is

$$\phi_i(t) = 2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau \tag{2.4}$$

where, for convenience, the angle of the unmodulated carrier wave is assumed to be 0 at t = 0. The frequency modulated wave is, therefore,

$$s(t) = B \cos[2\pi f_c t + 2\pi k_f \int_0^t m(\tau) d\tau]$$
 (2.5)

## B. CAPTURE EFFECT

Consider the case of two FM carriers,  $s_1(t)$  and  $s_2(t)$ , present at the demodulator input and in the same frequency band. It is well known in practice that the output of the demodulator is the message of the dominant carrier. That is, if

$$s_{1}(t) = B_{1} \cos[2\pi f_{c}t + 2\pi k_{f} \int_{0}^{t} m_{1}(\tau) d\tau]$$

$$s_{2}(t) = B_{2} \cos[2\pi (f_{c} + \epsilon)t + 2\pi k_{f} \int_{0}^{t} m_{2}(\tau) d\tau]$$
(2.6)

then the output of the demodulator is proportional to

$$m_1(t)$$
, when  $B_1 > B_2$ 

$$m_2(t)$$
, when  $B_1 < B_2$ 

The carrier frequency offset  $\epsilon$  is any value such that both  $s_1(t)$  and  $s_2(t)$  are in the same operating frequency band of the receiver/demodulator. This inherent ability of an FM demodulator to suppress weaker FM carriers is called capture effect.

The FM demodulator can be a phase locked loop, a slope detector which includes Foster-Seeley and ratio detectors, or a pulse counting discriminator.

# C. ANALYSIS

As shown by Eq. (2.3), the instantaneous frequency  $f_i(t)$  of a frequency modulated carrier is proportional to the message m(t) being carried. Consequently, it is claimed in the literature that the output voltage of a frequency demodulator is proportional to  $f_i(t) - f_c = \Delta f_i(t)$  [ Ref. 2: pp. 169–172 ]. This is indeed the case in practice when the demodulator input is a single frequency modulated carrier. However, it is not the case, because of the capture effect, when the demodulator

input is multiple frequency modulated carriers.

The instantaneous frequency of the sum of two frequency modulated carriers can be derived as follows. Let

$$v(t) = B_1 \cos \phi_1(t) + B_2 \cos \phi_2(t)$$
 (2.7)

Using trigonometric identities, Eq. (2.7) can be written as

$$v(t) = C\cos\phi_3(t) \tag{2.8}$$

where,

$$C^{2}(t) = B_{1}^{2} + B_{2}^{2} + 2B_{1}B_{2}\cos[\phi_{1}(t) - \phi_{2}(t)]$$
(2.9)

$$\tan \phi_3(t) = \frac{B_1 \sin \phi_1(t) + B_2 \sin \phi_2(t)}{B_1 \cos \phi_1(t) + B_2 \cos \phi_2(t)}$$
(2.10)

From Eq. (2.2), the instantaneous frequency  $f_i(t)$  is

$$f_{i}(t) = \frac{1}{2\pi} \left[ \frac{d}{dt} \phi_{3}(t) \right]$$

$$= \frac{1}{2\pi} \frac{d}{dt} \tan^{-1} \left[ \frac{B_{1}\sin\phi_{1}(t) + B_{2}\sin\phi_{2}(t)}{B_{1}\cos\phi_{1}(t) + B_{2}\cos\phi_{2}(t)} \right]$$

$$= \frac{(B_{1}\phi_{1}'\cos\phi_{1} + B_{2}\phi_{2}'\cos\phi_{2}) C + (B_{1}\phi_{1}'\sin\phi_{1} + B_{2}\phi_{2}'\sin\phi_{2})D}{2\pi(C^{2} + D^{2})}$$

$$= \frac{B_{1}^{2}\phi_{1}' + B_{2}^{2}\phi_{2}' + \left[ B_{1}B_{2}\cos(\phi_{1} - \phi_{2}) \right] (\phi_{1}' - \phi_{2}')}{2\pi[B_{1}^{2} + B_{2}^{2} + 2B_{1}B_{2}\cos(\phi_{1} - \phi_{2})]}$$
(2.11)

where,

$$C = B_1 \cos \phi_1(t) + B_2 \cos \phi_2(t)$$

$$D = B_1 \sin \phi_2(t) + B_2 \sin \phi_2(t)$$

and  $\phi_1$ ',  $\phi_2$ ' represent  $\frac{d}{dt}\phi_1(t)$  and  $\frac{d}{dt}\phi_2(t)$  respectively.

As before, for an FM carrier

$$\phi_{i}(t) = 2\pi f_{c}t + 2\pi k_{f} \int_{0}^{t} m_{i}(\tau) d\tau$$

$$\phi_{i}'(t) = 2\pi f_{c} + 2\pi k_{f} m_{i}(t) \qquad i = 1, 2$$
(2.12)

where the carrier frequencies for both messages are assumed to be the same and

$$m_i(t) = i \text{ th message}$$

 $k_f = {
m frequency\ sensitivity\ of\ the\ frequency\ modulator\ in\ Hertz/volt}$ 

Equations (2.8) through (2.12) can be reduced and interpreted for particular messages. For example, let the two messages be tones where

$$m_i(t) = D_i \cos 2\pi f_i(t)$$
  $i = 1, 2$  (2.13)

For simplicity, let  $D_1 = D_2 = 1$ . Then,

$$\phi_{i}(t) = 2\pi f_{c}t + 2\pi k_{f} \int_{0}^{t} \cos(2\pi f_{i}\tau) d\tau$$

$$= 2\pi f_{c}t + \frac{k_{f}}{f_{i}} \sin 2\pi f_{i}t$$

$$\phi'_{i}(t) = 2\pi f_{c} + 2\pi k_{f} \cos 2\pi f_{i}t \qquad i = 1, 2$$
(2.14)

Using these values in Eq.(2.11) gives

$$f_i(t) = \frac{f_c(B_1^2 + B_2^2) + k_f \cdot X + B_1 B_2 Y \cdot Z}{B_1^2 + B_2^2 + 2B_1 B_2 Z}$$
(2.15)

where

$$X = B_1^2 \cos 2\pi f_1 t + B_2^2 \cos 2\pi f_2 t$$

$$Y = 2f_c + k_f (\cos 2\pi f_1 t + \cos 2\pi f_2 t)$$

$$Z = \cos[2\pi k_f (\frac{1}{2\pi f_2} \sin 2\pi f_2 t + \frac{1}{2\pi f_1} \sin 2\pi f_1 t)]$$

Equation (2.15) is plotted in Figs. 2.1.a through 2.2.c along with  $m_1(t)$  and  $m_2(t)$  where  $f_1 = 1$  Hz and  $f_2 = 1.3$  Hz. It can be seen that there are many impulselike frequency deviations from the message waveforms. The variable in Fig. 2.1 is  $\beta$  (modulation index for FM). The bandwidth of the modulated carrier is related to  $\beta$ . In general, bandwith increases linearly with  $\beta$  [ Ref. 3: pp. 194–197].

There are two major factors that affect the graph of instantaneous frequency. First, the bandwidth of the modulated carrier affects the spacing in time between adjacent impulse—like frequency deviations. Figures 2.1.a through 2.1.c show that as the bandwidth decreases, the spacing increases. Second, the difference in magnitude of the two modulated carriers affects the extent of the deviation. Figures 2.2.a through 2.2.c show that as the magnitude difference increases, the deviation extent decreases.

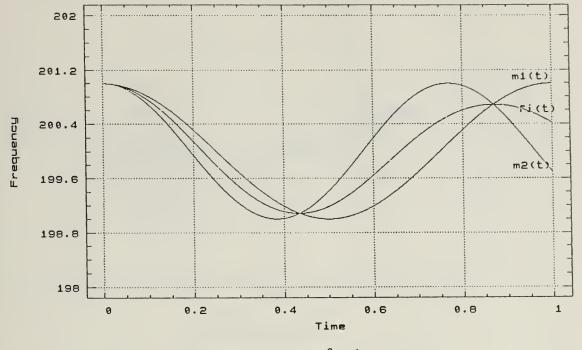
However, these results do not show specific evidence of capture. Rather, they suggest that the instantaneous frequency needs to be averaged over a short time interval to reveal the capture effect. The same thing is true for the case of close (but different) carrier frequencies, as shown in Chapter III.

The idea that the capture effect is caused by the lowpass filtering operation of frequency demodulation led to this research. Since lowpass filtering can be thought of as averaging (or smoothing), it was decided to investigate the capture effect by averaging the instantaneous frequency using a computer.

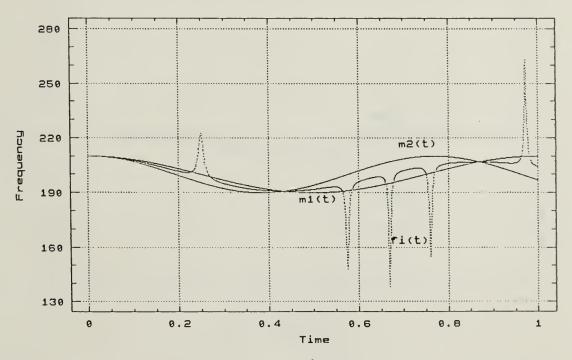
So, in hardware, the averaging is done by the lowpass filter (LPF). A LPF is part of every frequency demodulator (frequency—to—voltage or voltage—to-frequency converter). Consequently, the output of a frequency demodulator is a lowpass filtered version of instantaneous frequency deviation  $\Delta f_i(t)$ .

Again, lowpass filtering can be considered as a smoothing operation on the applied voltage. In this research, we used computer simulation to investigate the effect of smoothing of  $\Delta f_i(t)$  to reveal the presence of capture. Smoothing is created by averaging time intervals between adjacent zero crossings of the FM carrier. Since this interval  $(T_1)$  represents the time required for  $\pi$  radians excursion of the argument of the cosine carrier, and since  $\pi$  radians is taken as a half cycle, then two such intervals  $(T_1 + T_2)$  become a full cycle and  $\frac{1}{T_1 + T_2}$  is the number of cycles per second or the instantaneous frequency for  $T_1 + T_2$  seconds. Averaging N such groupings provides a smoothed value of or short—term average of the instantaneous frequency over that expanded time interval.

A computer program was used to approximate  $T_1$  and  $T_2$  for every interval between zeros of v(t). These values are then averaged and the results are plotted. The program is explained in Chapter III.







b.  $\beta = 10$ 

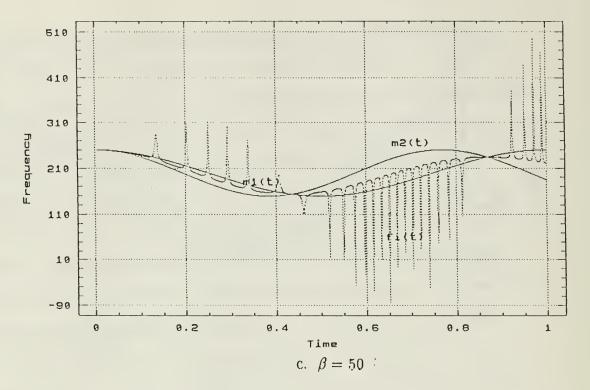
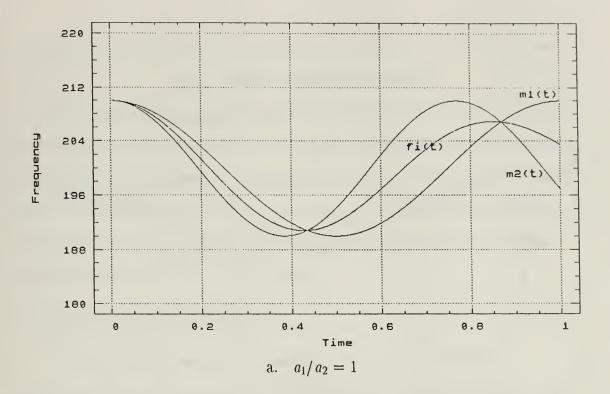
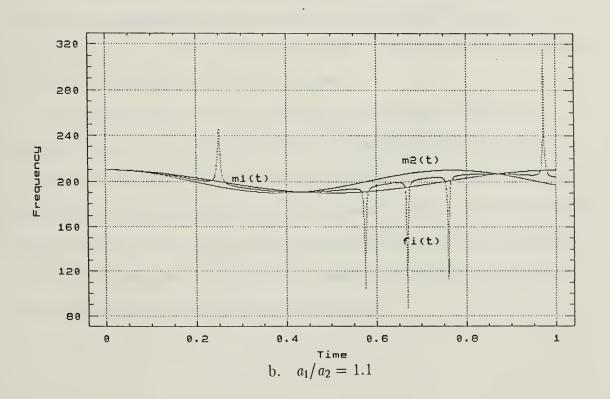


Fig. 2.1 Instantaneous Frequency for Tone Messages where  $a_1/a_2=1.2,\,f_c=200$  Hz,  $f_1=1$  Hz,  $f_2=1.3$  Hz





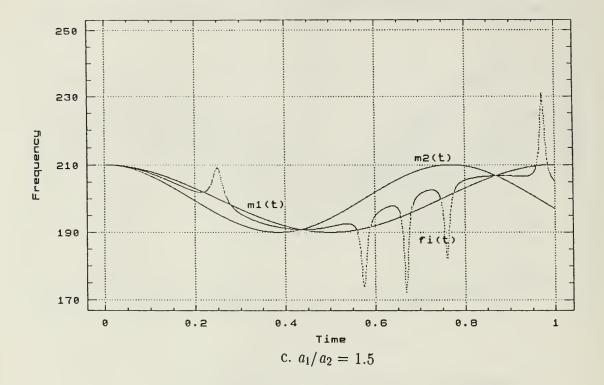


Fig. 2.2 Instantaneous Frequency for Tone Messages where  $\beta=10,\,f_c=200$  Hz,  $f_{\rm I}=1$  Hz,  $f_{\rm Z}=1.3$  Hz

#### III. SIMULATION PROCEDURE

The FM demodulator, including LPF, is simulated by a computer program so that critical parameters, such as signal amplitudes, bandwidth of the FM system, message forms, and interval of averaging, can be easily changed. Since the sampled version of the demodulator input forms a sequence of numbers, it is convenient to consider it as a row (or column) vector. Once that is done, the rest is simple manipulation of the row (or column) vector.

#### A. WAVEFORM GENERATION

The desired waveform v(t) can be generated using a simple routine (WAVEGEN). In this routine, the carrier amplitudes, values of  $k_f$ , carrier frequencies and message frequencies are input parameters which can be changed. This resulting wave is sampled at a rate which will provide the desired accuracy in measuring the time between adjacent zeros of v(t). In this work, a carrier frequency of 200 Hz and sampling rate of 12 kHz are used.

The sampled values contain no information about frequency. Rather, the number of samples between zero crossings are related to frequency because the number of samples between zero crossings itself represents a half cycle oscillation of argument of v(t) and its reciprocal can be interpreted as twice the frequency of that period. Therefore, the routine notes the polarity of each sample so that the number of samples between zero crossings (polarity changes) can be easily counted. This result is then used as the input for the next routine.

### B. COUNTING

The number of samples between zero crossings (polarity changes) multiplied by the fixed sampling interval  $(\lambda)$  is considered to be taken as half the instantaneous period of that interval. So, a sequence of integers which consists of the number of samples between zero crossings need only be generated. The i th entry for this sequence is denoted by  $T_i$ ,  $i=1,2,3,\cdots$  as shown in Fig. 3.1. The totality of entries forms a sequence of integers.

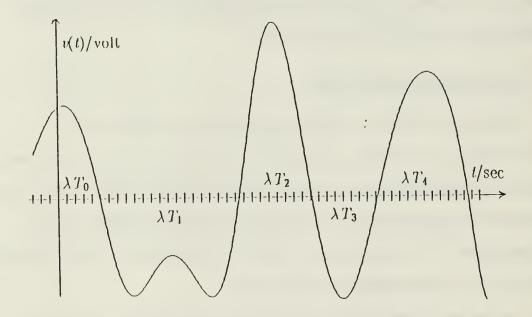


Fig. 3.1 Formation of sequence

Furthermore,  $T_i$  itself is a time index. Since there are i-1 entries before the current interval  $T_i$ ,  $T_i$  is the period for the time  $\sum_{k=1}^{i-1} T_k + \frac{1}{2} T_i$ . (The middle of the interval  $T_i$  is selected for the time index of interval  $T_i$ . For example, the time index of  $T_i$  is  $T_i + T_i + \frac{1}{2} T_i$ .)

Since the first and last interval may contain a number of samples that does not correspond to a complete interval between adjacent zeros, these two entries are not used in the averaging routine.

# C. AVERAGING

Given the sequence of integers, any average  $\overline{T}_k$  over N intervals is formed as

$$\bar{T}_k = \frac{\sum\limits_{k=1}^{k+N} T_i}{N} \qquad k = \text{any positive integer} \qquad (3.1)$$

 $T_i = i$  th interval

N = number of intervals averaged

Since frequency is taken as the reciprocal of the period, the averaged frequency, denoted by  $f_{\!k}$  , is given by

$$f_{k} = \frac{1}{2\,\overline{T}_{k} \lambda} \tag{3.2}$$

To obtain more realistic (smoother) results, a moving average is used rather than fixed time interval averaging. To illustrate this, assume a sequence of intervals as follows

$$T_1$$
  $T_2$   $T_3$   $T_4$   $T_5$ ....

Then, if the average is done over 3 intervals, the averaged version of the sequence will have the following entries

$$\bar{T}_1 = \frac{T_1 + T_2 + T_3}{3}$$

$$\bar{T}_2 = \frac{T_2 + T_3 + T_4}{3}$$

.

$$\bar{T}_{k} = \frac{T_{k} + T_{k+1} + T_{k+2}}{3} \tag{3.3}$$

Again from the relationship between period and frequency (Eq.(3.2)), averaged version of frequency will form the sequence

$$\frac{1}{2\bar{T}\lambda} \frac{1}{2\bar{T}_2\lambda} \cdots \frac{1}{2\bar{T}_k\lambda} \cdots$$

In this case, the time indices for the averaged version of intervals are

$$\frac{T_1+T_2+T_3}{2}=\text{ time index for }\bar{T}_1$$
 
$$T_1+\frac{T_2+T_3+T_4}{2}=\text{ time index for }\bar{T}_2$$
 
$$T_1+T_2+\frac{T_3+T_4+T_5}{2}=\text{ time index for }\bar{T}_3, \text{ and so on.}$$

Generally, time indices for the moving average over N intervals are found as

$$\frac{i-1}{k=1}T_k + \frac{1}{2} \frac{i+N-1}{k = i}T_k \quad \text{(time index for } \bar{T}_i\text{)}$$
(3.4)

Since the values of each  $T_i$  are not the same, the averaged frequency values when plotted will not be equally spaced.

#### IV. SIMULATION RESULTS

With an average of 2 intervals (N=2), the resulting plot is very similar to that of the analytical one. That is, when almost no averaging is done, the resulting plot should yield that of the analytical one. This is another way of verifying that the simulation program is running properly. As the number N of average intervals increases, the impulse—like frequency deviation becomes smaller and the overall frequency deviation approaches that of the stronger signal.

Figures 4.1.a through 4.5.c are the simulation results. The results are presented as averaged instantaneous frequency versus time. In all cases, the message  $m_1(t)$  corresponds to that of the dominant carrier. The following variables are used to see the effect of system parameters.

 $a_1/a_2$  = ratio of carrier amplitudes (1 through 1.5)

 $\beta$  = modulation index (1 for narrowband, 10 for wideband, 50 for very wideband FM)

 $f_1 = \text{message 1 frequency (1 Hz for sinusoidal message)}$ 

 $f_2$  = message 2 frequency (1.3 Hz for sinusoidal message)

 $f_c = carrier frequency (180 Hz through 200 Hz)$ 

N = number of intervals averaged (2, 20, 40, 60, 80)

Various messages were used in the simulation. Figures 4.1.a through 4.1.c show the results when the messages are linear intrapulse FM (up CHIRP and down CHIRP). Figures 4.2.a and 4.2.b are for exponentially decaying and growing sinusoidal messages. Sinusoidal messages are used extensively to show the results for various correlations of the listed variables.

Even though there may be other factors which influence the capture effect, only the following four factors are investigated in this research.

# A. EFFECT OF N (AVERAGING TIME)

Figures 4.3.a through 4.3.d shows the effect of N. The other factors  $(a_1/a_2, \beta, f_1, f_2, f_2)$  remain fixed. This factor is essentially the cause of the capture effect. As N increases, the instantaneous frequency increasingly resembles the message of the stronger signal.

#### B. EFFECT OF SIGNAL AMPLITUDE RATIO

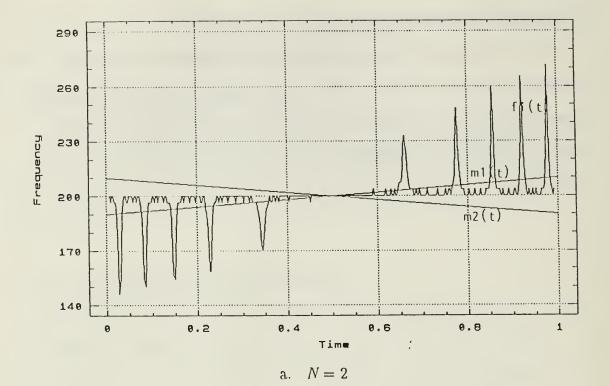
Figures 4.4.a through 4.4.d show the effect of signal amplitude difference. While the other factors remain fixed,  $a_1/a_2$  varies from 1.01 to 2.0. The effect of signal amplitude difference is very interesting. Even with very small signal amplitude difference, the system still locks onto the stronger signal. For numerical comparison, the 0.8 dB difference case (Fig. 4.4.b) and 1.6 dB case (Fig. 4.4.c) show little difference. In the case of very small amplitude difference, more averaging is needed to see the capture effect. Figure 4.4.a indicates capture for a carrier separation of 0.17 dB  $(a_1/a_2 = 1.02)$ .

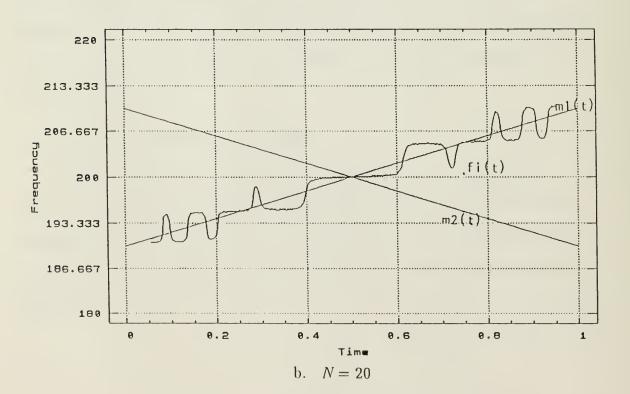
## C. EFFECT OF MODULATION INDEX

Modulation indicies are changed from 1 to 50 in Figs. 4.5.a through 4.5.c. Capture occurs for both narrowband FM and wideband FM. Since the narrower band FM shows fewer impulse—like frequency deviations, each of longer duration than those of wider band FM, narrow band FM needs to be averaged longer (see Fig. 2.1).

# D. EFFECT OF CARRIER FREQUENCY DIFFERENCE

Figures 4.6.a and 4.6.b show the effect of carrier frequency difference on capture. It appears that capture becomes more complete as the carrier frequencies separate. Obviously, the two carriers must lie in the passband of the receiver (intermediate frequency amplifier) if they are to be present at the input to the demodulator.





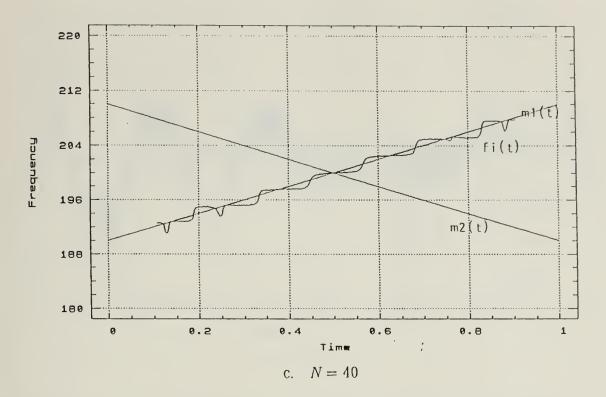


Fig. 4.1 Average instantaneous Frequency Deviation for CHIRPS where  $a_1/a_2=1.5$ 

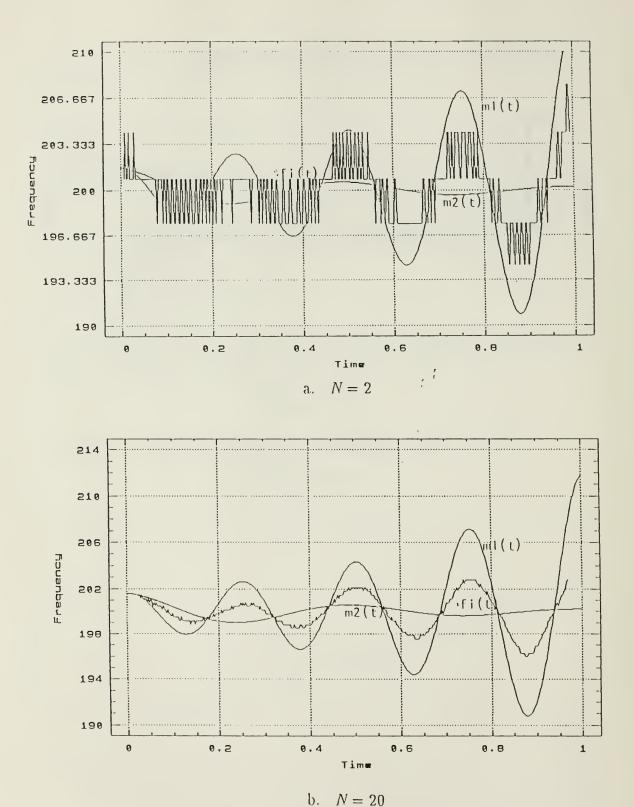
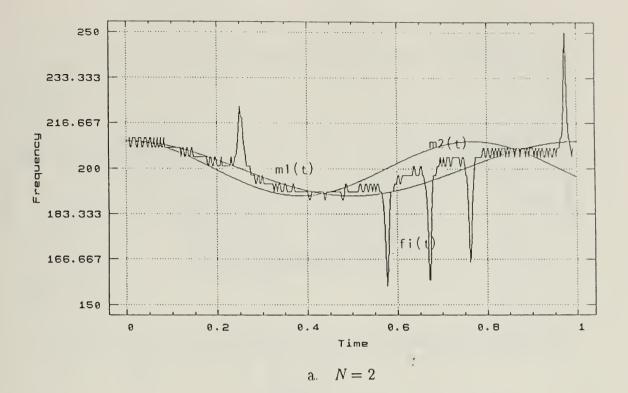
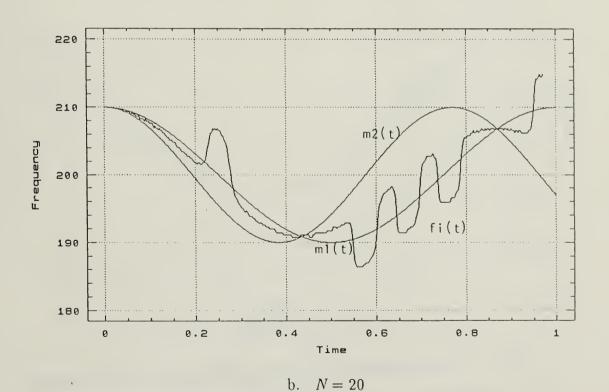


Fig. 4.2 Average Instantaneous Frequency Deviation for Decaying and Growing Sinusoidal Messages where  $a_1/a_2=1.2$ 





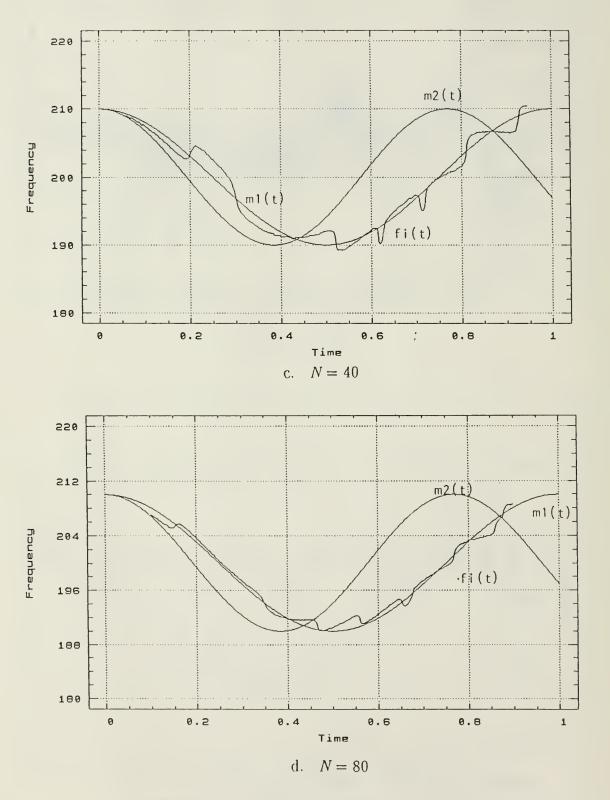
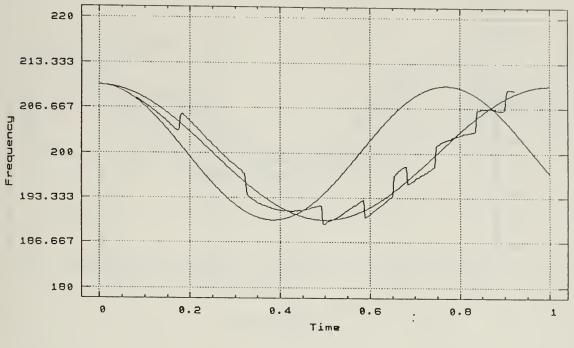
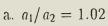
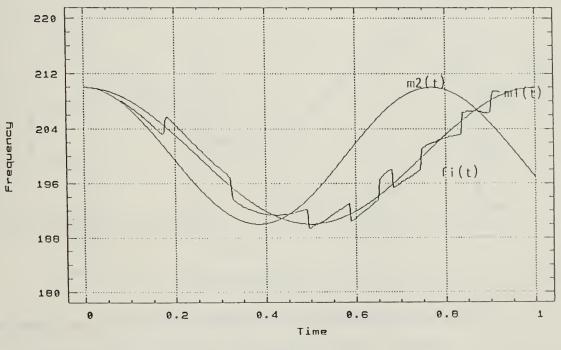


Fig. 4.3 Average Instantaneous Frequency Deviation for Tone Messages where  $a_1/a_2=1.2$ ,  $\beta=10$ ,  $f_c=200$  Hz,  $f_1=1$  Hz,  $f_2=1.3$  Hz







b.  $a_1/a_2 = 1.2$ 

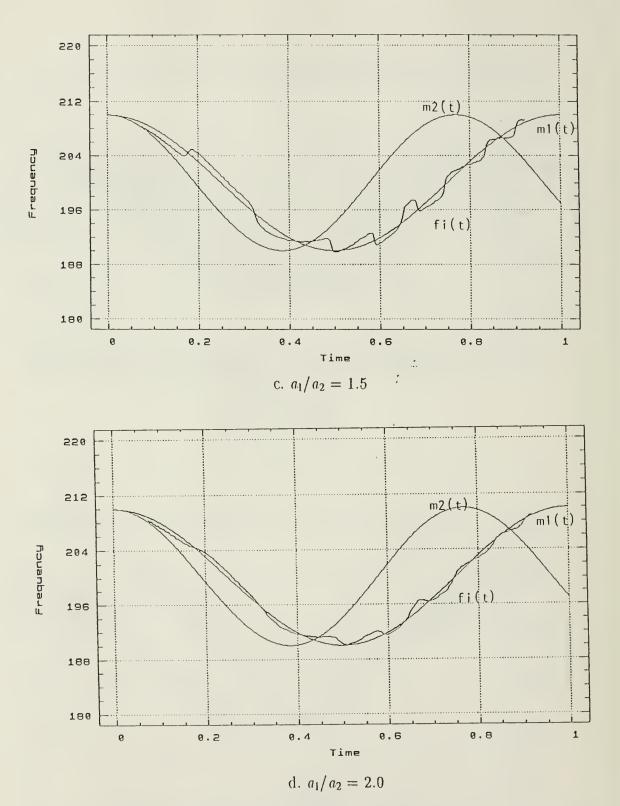
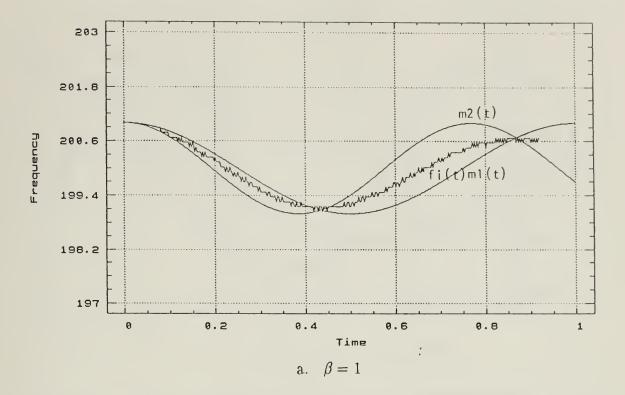
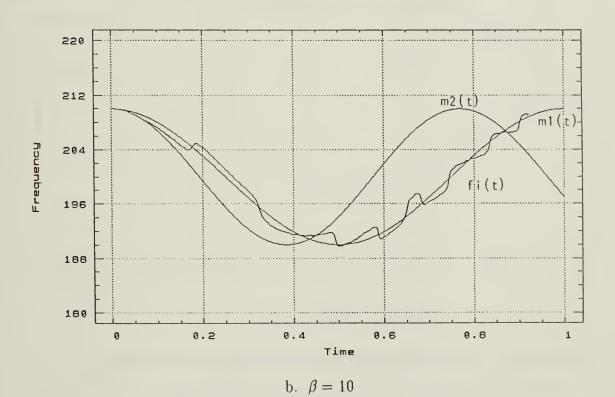


Fig. 4.4 Average Instantaneous Frequency Deviation for Tone Messages where  $\beta=10,\,f_c=200$  Hz,  $f_{\rm l}=1$  Hz,  $f_{\rm l}=1.3$  Hz, N=60





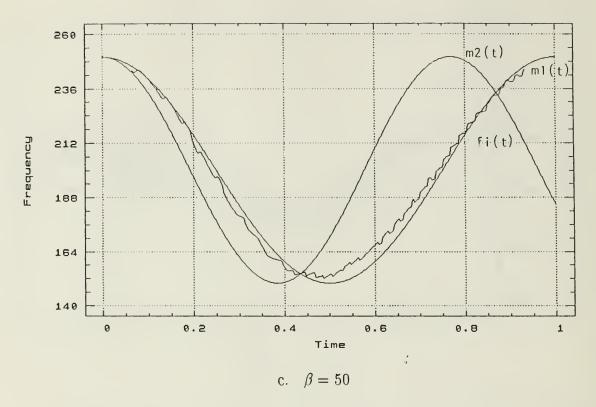
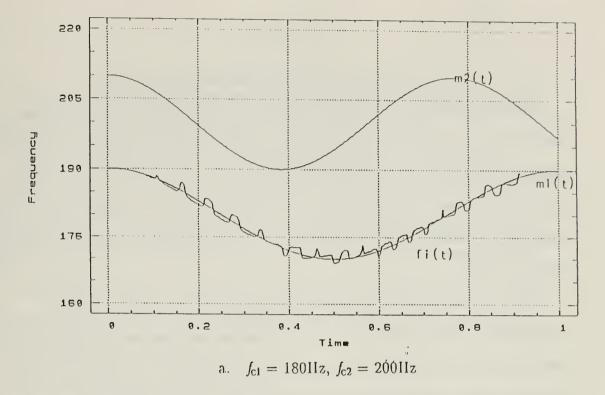


Fig. 4.5 Average Instantaneous Frequency Deviation for Tone Messages where  $a_1/a_2=1.2,\,f_c=200$  Hz,  $f_1=1$  Hz,  $f_2=1.3$  Hz, N=60



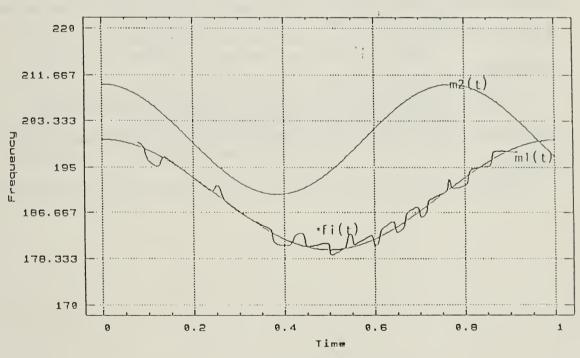


Fig. 4.6 Average Instantaneous Frequency Deviation for Tone Messages where  $a_1/a_2 = 1.2$ ,  $f_1 = 1$  Hz,  $f_2=1.3$  Hz,  $\beta = 10$ , N = 60

b.  $f_{c1} = 19011z$ ,  $f_{c2} = 20011z$ 

### V. CONCLUSIONS AND RECOMMENDATIONS

The simulation results establish that the lowpass filtering portion of frequency demodulation accounts for the capture effect of FM receivers. Without filtering, the instantaneous frequency deviation of the sum of two carriers has an impulse—like history which does not consistently favor the message of the dominant carrier. With averaging or smoothing (lowpass filtering) of the instantaneous frequency deviation, capture occurs.

The simulation results indicate capture occurs for both narrowband and wideband FM. Capture is evident when the carriers are separated in amplitude by less than 0.2 dB. The effect of averaging time is revealed by the simulation output. In general, longer averaging times produce smoother approximation to the message of the dominant carrier, as expected, and also show the capture effect more convincingly.

It is recommended that the capture effect be verified using an operating experimental system in which system parameters can be controlled and accurately measured.

## **APPENDIX**

## Program List

This appendix contains the program used to calculate  $f_i$  defined in the thesis. The program actually determines  $\bar{T}_i$  and  $\bar{T}_k$  as given by Eq. (3.1).

The input equation is  $s_1(t) + s_2(t)$  as defined by Eq.2.6. This equation is sampled 12,000 times in the one second simulation interval. The interval between samples is, then,  $1/12,000 = 83.3 \ \mu \text{sec} = \lambda$ . The polarity of each sample value is noted. The number of consecutive sample values of like polarity in interval i is  $T_i$ .

The program stores each value of  $T_i$  and forms  $\bar{T}_k$  from Eq. (3.1) for various assigned values of N. Then  $f_k$  is calculated according to Eq. (3.2). Finally,  $f_k$  is plotted for each time index of Eq. (3.4).

The program contents are following:

MAIN : main routine for the simulation of capture effect

CHIRPGEN : subfunction routine for generation of CHIRPs

WAVEGEN : subfunction routine for generation of sinusoidal waves

COUNT : subfunction routine for counting and averaging

SAMPLE : subfunction routine for display

The program was written in APL and run on IBM PC/AT with 3 Mb of memory.

#### A. MAIN

```
∇ Y←MΛIN Λ;Λ;Y;TMPSMP;TSLICE
[1]
    B
[2]
    n This is main routine for the capture effect
     n Simulation. For the clality of logical flow,
[3]
[4]
     A each simulation step is divided into their
[5]
     n own routines.
[6]
    A The output will be,
[7]
       T: time index for fl and f2
[8]
        TIME: time index for aceraged frequency
              (not equally spaced)
[9]
[10] A
       F1,F2: individual instantaneous
[11] A
               frequency
[12] n
       RES: averaged version of frequency
[13] A
[14]
[15]
      □←'Generating waves....'
[16]
[17] A Generating arbitrally sinusoidal waves
[18]
      TMPSMP+WAVEGEN A
[19]
[20]
      D←'Counting....'
[21]
[22] n Count the number samples between
[23] A zero crossings and form a resulting sequency
[24]
[25]
      Y←COUNT TMPSMP
[26]
     U←'Sampling....'
[27]
[28] A Since the numbers of elements of sampled time and
[29] A message are too many for plotting purpose, it is
[30] A sampled without missing any important information.
[31]
[32]
      T-SAMPLE T
[33]
     F1←SλMPLE F1
[34]
      F2←SAMPLE F2
      U←'Done.'
[35]
```

#### B. CHIRPGEN

```
▼ V←CHIRPGEN A1:DIO:A1:A2:PH1:PH2:V:TMP1:TMP
[1]
[2]
     A This routine generates two CHIRP signals, namely up
     A and down CHIRP to test the program.
[3]
     A Equations for this routine are,
[4]
          F1=100T+150 for up CHIRP
[5]
[6]
          F2=250-100T for down CHIRP
    A
[7]
     A where 0≤T≤1
[8]
[9]
      □IO←0
[10]
      A2←1
[11]
      TSLICE←「(1.3*0.5)×10000
[12]
      T←(iTSLICE)÷TSLICE
[13]
      D←50
[14]
      TMP+(02)×D
[15]
      TMP+TMP×T
[16]
      TMP+TMP×T
[17]
      TMP1 \leftarrow (02) \times (200 - D)
[18]
      TMP1←TMP1×T
[19]
      PH1←TMP+TMP1
[20]
      TMP \leftarrow (02) \times (200 + D)
[21]
      TMP+TMP×T
[22]
      TMP1 \leftarrow (02) \times D
[23]
      TMP1+TMP1×T
[24]
      TMP1←TMP1×T
[25]
      PH2←TMP-TMP1
[26]
      TMP←20PH1
[27]
     TMP1←20PH2
[28]
      TMP+A1×TMP
[29]
      TMP1←A2×TMP1
[30]
      V←TMP+TMP1
[31] V+xV
[32]
      F1←2×D×T
      F1+F1+200-D
[33]
[34]
      F2+200+D
[35]
       TMP←2×D
[36]
       TMP+TMP×T
[37] F2←F2-TMP
```

#### C. WAVEGEN

```
∇ V←WAVEGEN A1; □IO; A1; A2; V; TMP1; TMP; V1; V2; KF1; KF2

[1]
      :FC1:FC2:FM1:FM2:PH1:PH2:P1:P2
[2]
[3]
     A Routine to generate samples of sinusoid waveforms
[4]
[5]
      DIO←0
[6]
     A Second wave amplitude. This routine accepts the first
[7]
     A signal amplitude as an input argument
[8]
[9]
[10]
     A2←1
[11]
     P2←02
[12]
      TSLICE←「(1.5*0.5)×10000
[13]
      T+(tTSLICE) ÷TSLICE
[14]
[15] A Carrier frequency, frequency sensitivity and message
[16] A frequency
[17]
[18]
      FC1←200 ♦ FC2←200
     KF1←10 ♦ KF2←10
[19]
     FM1←1 ♦ FM2←1.3
[20]
[21]
     PH1←0 ♦ PH2←0
[22]
      TMP←P2×FM1
[23]
      TMP+TMP×T
[24]
      TMP←TMP+PH1
[25]
      TMP←10TMP
[26]
      TMP←TMP-(10PH1)
[27]
      TMP←TMP×KF1÷FM1
[28]
      TMP1←P2×FC1×T
[29]
      TMP←TMP+TMP1
[30]
      V1←20TMP
[31]
      V1+V1×A1
[32]
      TMP←P2×FM2
[33]
      TMP+TMP×T
[34]
      TMP←TMP+PH2
[35]
      TMP←10TMP
[36]
      TMP←TMP-(10PH2)
[37]
      TMP←TMP×KF2÷FM2
[38]
      TMP1←P2×FC2
[39]
      TMP1←TMP1×T
[40]
      TMP←TMP+TMP1
[41]
      V2←20TMP
[42]
      V2←A2×V2
[43]
      V \leftarrow \times (V1 + V2)
[44]
      TMP←P2×FM1
[45]
      TMP+TMP×T
[46]
      TMP←TMP+PH1
[47]
      TMP+KF1×COS(TMP)
[48]
      F1←FC1+TMP
[49]
      TMP←P2×FM2
[50]
      TMP+TMP×T
[51]
       TMP←TMP+PH2
[52]
       TMP←KF2×COS(TMP)
[53]
       F2←FC2+TMP
```

#### D. COUNT

```
▼ Y+COUNT V;C;COUNTER;INIT:I:LIMIT:D:Y:TMP
[1]
      ;EXTIME1;EXTIME2:INTV
[2]
[3]
     aRoutine to form half period sequence and average it
[4]
[5]
[6]
     A Set the initial matricies and values
[7]
    C+0
[8]
[9]
      COUNTER←0
[10] INIT+V[DIO]
[11]
      I←DIO
[12]
     LIMIT \leftarrow (\rho V) + \Box IO - 1
[13] A
[14] A Routine to count number of samples between
[15] A Zero-crossings
[16] A
[17] LOOP1:
[18] \rightarrow(V[I]=INIT)/LOOP2
[19] C+C.COUNTER
[20] INIT+V[1]
[21] COUNTER←1
[22] →LOOP3.
[23] LOOP2:
[24]
     COUNTER+COUNTER+1
[25] LOOP3:
[26] I+I+1
[27] \rightarrow (I\leqLIMIT)/LOOP1
[28] C+C, COUNTER
[29] A
[30] A Drop the incomplete cycle at the beginning and the end
[31] A
[32]
     EXTIME1←C[DIO]×(1÷TSLICE)
      C←1↓C ♦ C←-1↓C
[33]
[34]
      D←Ð
[35] TIME←0
[36] A
[37] A Average with the value of INTV
[38] A
[39] INTV+60
[40]
      I←□IO
[41] LIMIT\leftarrow(\rhoC)-(\squareIO+1+INTV)
[42] A
[43] A Calculate extra time due to averaging
[44] A
[45] EXTIME2+(+/INTV1C)+TSLICE
[46] A
[47] A Calculate the time index which is not equally placed
[48] A
[49] LOOP4:
[50] TMP++/INTV1C
     D←D,TMP÷INTV
[51]
[52] TIME+TIME,C[UIO]
[53] C←1↓C
[54] I+I+1
```

```
[55] →(I≤LIMIT)/LOOP4
[56] TIME←((+\TIME)÷TSLICE)+EXTIME1+(EXTIME2÷2)
[57] A
[58] A Calculate averaged frequency for the time indicies
[59] A
[60] Y←(1÷2×D)×TSLICE
```

### E. SAMPLE

```
▼ Y←SAMPLE X; DIO; Y; SIZ; LIMIT; I; X
[1]
[2]
      A Routine to sample for plotting (number of samples = 60
[3]
[4]
       □IO←0
[5]
       V←Ð
[6]
       SIZ \leftarrow l((\rho X) \div 600)
[7]
       LIMIT \leftarrow (\rho X) + \Box IO - 1
[8]
       I←□IO
[9]
     LABEL1:
[10] Y \leftarrow Y, X[I \times SIZ]
[11] I+I+1
[12] \rightarrow((I×SIZ)\leqLIMIT)/LABEL1
```

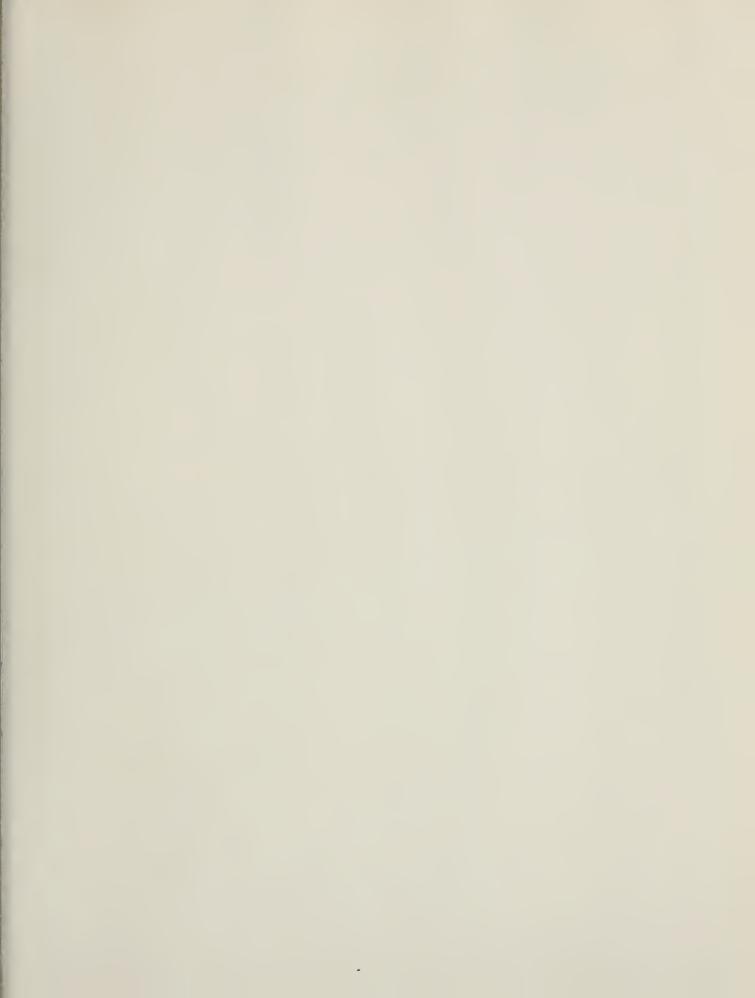
## LIST OF REFERENCES

- 1. Keiser, B. E., Broadband Coding, Modulation, and Transmission Engineering, Prentice Hall, 1989.
- 2. Taub, H., and Schilling, D. L., *Pinciples of Communication Systems*, McGraw—Hill Book Co., 1986.
- 3. Haykin, S., Communication Systems, John Wiley & Sons, Inc., 1983.

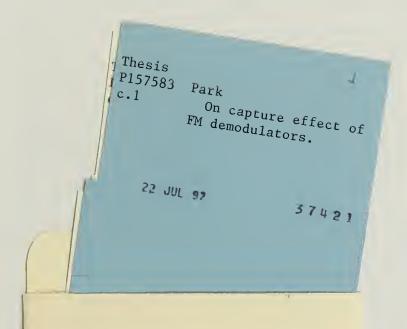
# INITIAL DISTRIBUTION LIST

|     |  | No. Copies |
|-----|--|------------|
| 1.  | Defense Technical Information Center<br>Cameron Station<br>Alexandria, VA 22304–6145   | 2          |
| 2.  | Library, Code 0142<br>Naval Postgraduate School<br>Monterey, CA 93943-5000   | 2          |
| 3.  | Office of the Chief of Naval Operations<br>Code OP-941<br>Washington, D.C. 20350-2000  | 1          |
| 4.  | Commander, Naval Telecommunications Command<br>Naval Telecommunications Command Headquarters<br>4401 Messachusetts Avenue, NW<br>Washington, D.C. 20390—5290 | 1          |
| 5.  | Library, P.O.Box 77<br>GongNeung-Dong,<br>DoBong-Ku, Seoul<br>Republic of Korea, 130-09  | 1          |
| 6.  | Prof. G. A. Myers, Code 62Mv<br>Dept. of Electrical and Computer Engineering<br>Naval Postgraduate School<br>Monterey, CA 93943-5000                         | 8          |
| 7.  | Prof. R. Panholzer, Code 62Pz<br>Dept. of Electrical and Computer Engineering<br>Naval Postgraduate School<br>Monterey, CA93943—5000                         | 1          |
| 8.  | Park, SoonSang<br>797—4, SangBongSeo—Dong<br>JinJu—City, KyeungNam—Do,<br>Republic of Korea, 620—00  | 5          |
| 9.  | Park, NaiSoo<br>130–26, DoGog 1–Dong,<br>Kangnam–Ku, Seoul,<br>Republic of Korea, 130–270  | 1          |
| 10. | Kim, Yong Joo<br>SMC 1017,<br>Naval Postgraduate School<br>Monterey, CA 93943  | 1          |

| 11. | Seo, Yong Suk<br>SMC 1448,<br>Naval Postgraduate School<br>Monterey, CA 93943 | 1 |
|-----|---|---|
| 12  | Shin, Eun Suk<br>SMC 2961,<br>Naval Postgraduate School<br>Monterey, CA 93943 | 1 |







Thesis
P157583 Park
c.1 On capture effect of
FM demodulators.



On capture effect of FM demodulators.

3 2768 000 81837 1 DUDLEY KNOX LIBRARY